UNIVERSITÉ DE SHERBROOKE

Faculté des sciences de l'activité physique

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Using video simulations and virtual reality to improve decision-making skills

Par

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Résumé

La littérature supporte l'efficacité d'un entraînement employant des simulations vidéos afin d'améliorer la performance sur le terrain lors d'une tâche d'interception (par exemple : frapper une balle de baseball). Son efficacité pour une tâche d'invasion qui requiert la localisation de coéquipiers et d'adversaires afin de choisir l'action optimale a été démontrée en laboratoire, toutefois le transfert de gains de performance entre le laboratoire et le terrain n'a pas été démontré. Une des raisons pouvant expliquer cette absence de transfert est le niveau relativement modeste d'immersion qu'offre les simulations vidéos utilisant un écran d'ordinateur ou une télévision, un facteur qui a été suggéré comme étant crucial pour des séances d'entrainement vidéos. À cet effet, il est à noter que des progrès technologiques récents permettent aux spectateurs de visionner des vidéos avec un niveau d'immersion élevé dans l'action en utilisant la réalité virtuelle. Il est donc possible que les simulations vidéos en réalité virtuelle puissent être bénéfiques pour l'entraînement à la prise de décision. L'objectif du présent mémoire est donc d'étudier l'influence de l'utilisation des simulations vidéos et de la réalité virtuelle afin d'améliorer la prise de décision. Pour ce faire, 27 joueurs de basketball experts ont participé à quatre séances d'entrainement pendant lesquelles ils ont observé des séquences vidéos de situations de jeu de basketball réalisées pour les besoins de l'étude et présentées soit sur un écran d'ordinateur (groupe CS) en utilisant un casque de réalité virtuelle (groupe VR), ou ils ont regardé des séquences de matchs universitaires de niveau NCAA sur un écran d'ordinateur (groupe CTRL). La prise de décision a été évaluée sur le terrain avant et après les quatre séquences d'entrainements en utilisant deux catégories de jeux : des jeux « entrainés » (jeux présentés pendant les entrainements CS et VR) et des jeux « non-entrainés » (jeux présentés seulement durant les évaluations sur le terrain). Nos résultats ont montré que les participants des groupes VR et CS ont été significativement meilleurs que les participants du groupe CTRL lorsque confrontés aux jeux « entrainés » lors de l'évaluation sur le terrain en posttest (moyenne de l'exactitude de la prise de décision de 79.0%, 73.2% et 57.5%, respectivement). Toutefois, lors des jeux « non-entraînés », seuls les participants du groupe VR ont montré une prise de décision supérieure comparativement aux participant du groupe CTRL (moyenne de l'exactitude de la prise de décision de 78.9%, 60.9% et 60.2%, pour les groupes VR, CS et CTRL, respectivement). Nos résultats montrent ainsi que les simulations vidéos en utilisant un écran

d’ordinateur mènent à un transfert des gains de performance spécifique aux jeux entrainés tandis que la réalité virtuelle mène non seulement à un transfert des gains de performance pour les jeux entrainés mais également à une généralisation de l’apprentissage vers les jeux nouveaux. Finalement, ces résultats suggèrent que l’entrainement CS améliore la reconnaissance de patrons de jeux spécifiques tandis que l’entrainement VR améliore les processus cognitifs impliqués dans l’échantillonnage de l’information qui sont généralisable aux jeux nouveaux.

Abstract

A large body of literature supports the effectiveness of video simulation to improve on-court/on-field performance in interceptive tasks (e.g., hitting a baseball). Its effectiveness for invasion tasks requiring the localization of teammates and opponents to select the optimal action has been demonstrated in the laboratory, however transfer of performance gains to the field has yet to be demonstrated. One possibility that could account for the lack of transfer is the relatively modest level of immersion afforded by video simulations using a TV/computer screen, a factor that has been suggested as critical for video training sessions. In this regard, it is noteworthy that modern technology can now afford viewers with an enhanced sense of immersion in the action while using virtual reality. With this in mind, whether presenting video simulations in virtual reality provides an added-value is unknown. Therefore, the present thesis investigates the effect of using video simulations and virtual reality to improve decision-making skills. To do so, 27 varsity-level basketball players underwent four training sessions during which they observed custom-made video clips of basketball plays presented either on a computer screen (CS group), using a virtual reality headset (VR group), or watched footage from NCAA playoff games on a computer screen (CTRL group). Decision-making skills were tested on-court before and after the four training sessions using two types of play: "trained" plays (plays presented during the CS and VR training sessions) and "untrained" plays (plays presented only during the on-court tests). Our results revealed that participant of the VR and CS groups significantly outperformed participants of the CTRL group when facing the “trained” plays during the on-court posttest (mean decision-making accuracy of 79.0%, 73.2% and 57.5%, respectively). However, when facing “untrained” plays, only participants of the VR group demonstrated better decision-making compared to participants of the CTRL group (mean decision-making accuracy of 78.9%, 60.9% and 60.2%, VR, CS, and CTRL groups, respectively). Our results demonstrate that video simulation using a computer screen leads to play specific transfer of performance gains, whereas using a virtual reality headset leads to play specific transfer of performance gains as well as a generalization of learning to novel plays. These results suggest that CS training results in improving pattern recognition of specific plays while VR training results in improving information sampling processes which are generalizable to novel plays.

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1. Introduction

Every year there is a substantial amount of money invested into high level sports. From the physical, psychological, and emotional development of athletes all the way to the media outputs of the performances of the athletes, billions of dollars are invested into this industry. From the 2016-2017 season to the 2024-2025 season, television broadcasting companies, such as *ESPN, ABC* & *TNT*, are paying the National Basketball Association 24 billion dollars simply to have the rights to broadcast the competitive matches played in this league (NBA extends television deals, 2016).

Athletes participate in countless hours of training on-field/on-court, in the weight room and in video sessions. The objectives of these sessions are to help athletes increase their performance at not only executing appropriate movements (e.g., shooting a basketball) but also improving their decision-making to execute movements (e.g., deciding to shoot, pass or dribble in basketball). A large body of literature supports the importance of decision-making as a critical skill for the development of expertise in a sporting context (Mann, Williams, Ward & Janelle, 2007; Müller & Abernethy, 2012; Williams, 2000). Furthermore, it has been well established that physical practice is the most effective method for athletes to reach the highest levels of performance (see Ericsson, 2006 for review).

However, when physical practice is limited or unavailable, especially at the amateur level due to limited access to facilities, to injuries or physical exhaustion, alternative training methods have to be utilized in attempts to improve decision-making. The upcoming thesis discusses a popular alternative training method for improving decision-making, namely video simulations.

2. What is decision-making

Over the last several decades, information processing has been an important topic of research when attempting to understand how humans acquire, interpret and use knowledge. The information acquired comes in many forms of sensory stimuli such as visual (e.g., seeing a basketball), auditory (e.g. hearing a dog bark), tactile (e.g., touching the spines of a cactus), olfactory (e.g. smelling a freshly baked pie) and others (Coles, Gratton, Bashore, Eriksen & Donchin, 1985; Schneider & Shiffrin, 1977).

Traditionally, information processing models have been composed of different stages (i.e., stimulus identification, response selection, response programming and response execution, Figure 1, Schmidt, Lee, Winstein, Wulf & Zelaznik, 2018). In this model, the sensory information is received and recognized by the appropriate system (e.g. the visual system acquires information about an incoming basketball) and the system then interprets the received information in order to select the appropriate response for the given situation (e.g. deciding to attempt to catch the basketball). An output representation of the selected decision is sent to the response programming stage (e.g. programming the motor movements required to attempt to catch a basketball). Finally, an output representation of this program is sent to be executed using areas in the brain such as the primary motor cortex, posterior parietal cortex, premotor cortex and supplementary motor area (e.g. raising the arms and hands to intercept and catch the basketball) (Schmidt & al., 2018).

Since the final two stages of information processing occur after the decision has been made, the upcoming theoretical foundations will expand on the first two stages, namely stimulus identification and response selection.

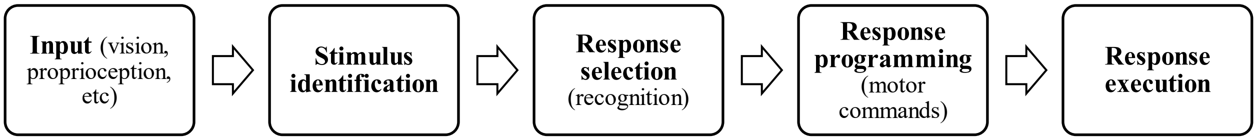


Figure 1 - Information processing model (Adapted from Schmidt et al., 2018).

2.1 **Stimulus Identification**

According to the information processing model (Schmidt et al., 2018), decision-making first involves the stimulus identification stage in which an individual samples the sensory information in his/her environment. Sensory information sampling is the acquisition of various stimuli which are present in the environment (Juni, Gureckis & Maloney, 2016). In a sporting context for example, this means acquiring visual information about an opponent's kinematic cues, patterns of play for team sports as well as object localization. Yet, sporting contexts are rich in information and not everything that is perceived is relevant to an athlete's decision process. For example, while an athlete may see banners held by the fans and hear encouragement chants coming from the crowd, this information is irrelevant in helping him/her decide what action is the most appropriate to stop the opponent coming towards him/her. With this in mind, it has been well established that an individual who is considered elite in his or her respective domain will show enhanced selective information processes when searching for relevant pieces of information in his/her environment (Ripoll, Kerlirzin, Stein, & Reine, 1995; Vickers, 1992). For instance, Goulet, Bard & Fleury (1989) investigated whether expert tennis players were better at predicting the location of a serve compared to novice players. The authors used a temporal visual occlusion paradigm in which the participants watched a video projection of a tennis serve (1st person point-of-view) which could be stopped at various moments during the serve (prior to ball contact, at ball contact, or after ball contact). Participants were then asked to predict where the ball would land. Not surprisingly, experts were generally better at predicting the location of the serve compared to their novice counterparts. Interestingly, the authors also reported a difference in the gaze behavior of the participants: the experts focused their attention on the arm and racquet of their opponent (i.e. relevant information), while the novices focused their attention mainly on the ball (i.e. irrelevant information). These results suggest that the experts' higher success rate in predicting the location of the serves was associated with their capacity to pay attention to visual information of higher relevance for the task (Goulet, Bard & Fleury, 1989). It has been well documented that experts focus their attention on information of higher relevance in several sports such as tennis (Smeeton, Williams, Hodges & Ward, 2005; Williams, Ward, Knowles & Smeeton, 2002; Goulet, et al., 1989), soccer (Savelsbergh, van Gastel & Van Kampen, 2010; Hopwood, 2009; Williams & Davids, 1998) and cricket (Brenton, Muller & Mansingh, 2016; Renshaw & Fairweather, 2000; Houlston & Lowes, 1993).

While we know that experts are better at identifying relevant information, a common strategy employed in many sports consists in hiding the relevant stimuli in purposefully produced deceptive movements which look relevant but are not. For example, a deceptive movement in rugby could include performing a 'side-step' in which the deceiver will try to give the impression of moving in one direction (i.e. irrelevant information) while going in the other (i.e. relevant information) (Jackson, Warren & Abernethy, 2006). This deceptive movement can create an information overload exceeding the attentional capacity of the individual. Thus, when an individual samples and focuses his/her attention on information in his/her environment (i.e. stimulus identification), his/her attentional resources are taxed by every sampled piece of information. These attentional resources are limited (Marois & Ivanoff, 2005), thus stressing the importance of differentiating relevant versus irrelevant information during a sporting event (Canal-Bruland & Schmidt, 2009; Jackson et al., 2006; Reilly & Williams, 2000). As mentioned above, experts are better at identifying relevant information. However, experts have also shown enhanced information processing skills when avoiding deceptive movements (Jackson et al., 2006), meaning that expertise is a result of several contributing factors.

2.2 **Response selection**

According to the information processing model, the second stage of decision-making involves response selection in which in an individual interprets the information acquired during the stimulus identification stage in order to select the best response. In a sporting context for example, this means interpreting the visual information about an incoming soccer ball or player movement on the basketball court. This interpretation is influenced by factors such as anticipation, that is to predict the outcome before the decision making process is completed, and previous experiences. These are critical components in sports, especially when severe temporal constraints are present (e.g. hitting a baseball) (Kida, Oda & Matsumura, 2005).

For instance, action prediction was studied with squash players from different expertise levels. Abernethy, Gill, Parks & Packer (2001) investigated whether expert squash players were better at predicting the upcoming shot of their opponent compared to their novice counterparts. The authors used liquid-crystal occlusion spectacles in which participants were instructed to anticipate the upcoming shot of their opponent by completing the return stroke while occlusion occurred at quasi-random instances up to 620 ms prior to ball contact. A visual occlusion occurring at 620 ms prior to racquet-ball contact resulted in the shots being predicted without the use of kinematic cues as the opponents had yet to commence their movements to execute the upcoming shot. This early occlusion resulted in participants needing to use other sources of information than kinematic cues in order to anticipate the upcoming shot. The expertise advantage therefore lied in previous experiences regarding the most probable upcoming shot based on preferred stroke and patterns of the their opponents. Thus, expertise seems to allow a priori knowledge of the opponents such as their ability to recall and/or recognize patterns of play which facilitates anticipation and response selection (Abernethy, Baker & Côté, 2005; Abernethy, Gill, Parks & Packer, 2001; Gorman, Abernethy & Farrow, 2012; Gorman, Abernethy & Farrow, 2013; Vicente & Wang, 1998).

Given these points, it is well established that expert decision-making is a result of several contributing factors such as sampling information of high relevance, avoiding deceptive movements, and using previous experiences as a tool for accurate anticipation. As mentioned at the start of the thesis, physical practice has been shown as the most effective tool to develop these skills underlying expert decision-making (Ericsson, 2006). However, when physical practice is limited or unavailable, alternative training methods have been utilized in attempts to improve decision-making. The following sections will explore the most often used training method in a sporting context to improve decision-making, namely video simulations.

3. Improving decision-making using video simulations

The upcoming sections will provide information regarding various video simulation training methods used to improve the decision-making skills of athletes. First of all, video simulation training will be defined and explained. Secondly, key variables to consider when creating video simulation training will be presented (more specifically, the camera angle, the type of response required from the participants, the speed of the videos, the size of the screen, and the viewing modality). Finally, the potential for this training modality to lead to on-court/on-field performance gains will be discussed.

3.1 **Video simulation training**

As mentioned previously, when physical practice is limited or unavailable, a popular method for training perceptual-cognitive skills (such as anticipation, decision-making and pattern recall) is video simulations. When creating video simulations, researchers typically acquire sport-specific footage of professional-level matches. (Gorman & Farrow, 2009; Lorains, Ball & MacMahon, 2013a; Breed, Mills & Spittle, 2011) or use actors to recreate mock situations (Gabbett, Rubinoff, Thorburn & Farrow, 2007; Abernethy, Schorer, Jackson & Hagemann, 2012; Hopwood, Mann, Farrow & Nielsen, 2011; Kinrade, Jackson & Ashford, 2015; Murgia, Sors, Muroni, Santoro, Prpic, Galmonte & Agostini, 2014; Poulter, Jackson, Wann & Berry, 2005; Williams, Ward & Chapman, 2003). Once the footage is acquired, researchers edit the videos to create training clips using the visual temporal occlusion paradigm. A classic example of this paradigm is an anticipation task where the participants need to predict the direction of a soccer ball hit towards them. The video clips are edited to be occluded at various moments such as prior to foot-ball contact, at foot-ball contact and after foot-ball contact (Poulter et al., 2005). Once the videos are stopped by the experimenter, participants have to respond as quickly and accurately as possible to intercept the virtual object. Researchers often attempt to improve either decision time, decision accuracy, or both, when using video simulation training. Finally, video simulation training is typically classified into two distinct categories regarding the type of task: interceptive and invasion. The former is often characterized by hitting an object (e.g. baseball or tennis) or catching/blocking an object (e.g. goalkeeping in soccer or hockey) (Craig, 2013). During an interceptive task, the level of success is predominantly determined by sampling information regarding body cues to anticipate the location of the object to be intercepted (Gabbett et al., 2007). During an invasion task, athletes attempt to score points/goals by attacking the defensive system or prevent the opposing team from scoring points/goals by defending against the offensive system. Invasion tasks require athletes to continuously adapt their behavior to the behavior of others, teammates and opponents, who are in close proximity (Davids, Araujo, Hristovski, Passos & Chow, 2012). During an invasion task, recognizing the accurate pattern of play based on the movements of the surrounding players is crucial to the collective success of the team.

3.2 **Camera angle**

When creating video simulation training videos, researchers have different possibilities to choose from. When researchers use professional-level game footage, the videos are from a third person perspective or an aerial view (similar to the broadcast view on television). Since actors are not required for this camera angle, it is viewed as a non-invasive method. Furthermore, it provides more information regarding available space on the court/field and more information regarding the position of attackers and defenders in relation to each other (Hopwood, 2009).

When researchers acquire their own footage, videos are most often from a first person perspective or egocentric (the player's perspective) (figure 2a for interceptive task; figure 2b for invasion task). This perspective provides stimuli to the participants that are closer to those experienced during actual competition. The quantity of information regarding available space on the court/field and the position of other players is lower compared to the aerial perspective.

However, this amount of information is closer and more specific in regards to the information accessible during competitive matches (Broadbent, Causer, Williams & Ford, 2015; Hopwood, 2009).

a

b

Figure 2a - Screenshot of an interceptive task from the egocentric point of view (Broadbent, Causer, Williams & Ford, 2015).

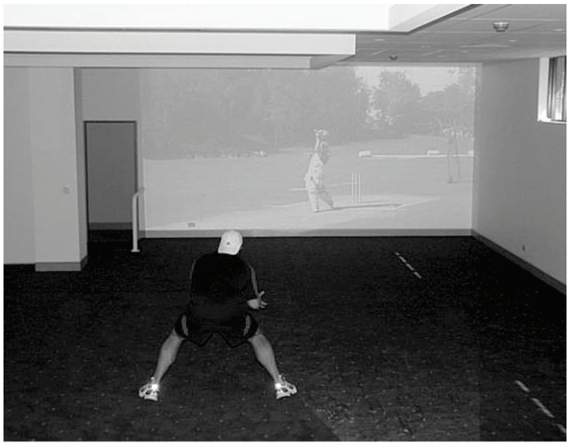
Figure 2b - Screenshot of an invasion task from the egocentric point of view (Pagé, Bernier & Trempe, submitted).

When it comes to using these viewing perspectives to train decision-making in the laboratory, the literature revealed very similar results for both interceptive and invasion tasks. For example, decision-making skills were studied in an Australian football and softball setting. The football study used training videos from an aerial perspective while the softball study used training videos from the player's perspective. Decision-making was evaluated, in both studies, in the laboratory during a pre- and posttest and included training sessions in the laboratory. Both studies revealed significant improvements for decision-accuracy from pre- to posttest (Gabbett et al., 2007; Lorains et al., 2013a). Similar results have been revealed for the aerial perspective (Gorman & Farrow, 2009) and the player's perspective (Abernethy et al., 2012; Hopwood et al., 2011; Gray, 2017; Murgia et al., 2014; Poulter et al., 2005). Based on these results, when decision-making is studied in the laboratory, performance changes occur similarly regardless of the viewing perspective as long as the pre- and posttests use the same camera angle as training.

3.3 **Type of response**

During video simulation training, experimenters ask participants to perform either a coupled or an uncoupled task. The former's objective is to not only predict an upcoming event (e.g., location of a kicked soccer ball) but includes the movement production aspect as well (e.g., moving in an accurate spatiotemporal manner to intercept a soccer ball or pass the basketball to the appropriate teammate) **(**Figure 3a for example). This type of response requires movements that are similar to those expected on the field/court (Figure 3b) which is its main advantage due to its closeness to the specificity of practice principle (Gabbett et al., 2007; Hopwood et al., 2011; Vignais, Kylpa, Brault, Presse & Bideau, 2015). The latter's objective is to predict an upcoming event (e.g. the appropriate teammate to pass the ball to) while using responses such as verbal (Murgia et al., 2014; Poulter et al., 2005) or clicking of a mouse or keyboard key (Abernethy et al., 2012; Gorman & Farrow, 2009; Lorains et al., 2013a).

a



b

Figure 3a – Video simulation of the cricket study from the egocentric point of view (Hopwood, Mann, Farrow & Nielsen, 2011).

Figure 3b - On-field transfer test of the cricket study (Hopwood, Mann, Farrow & Nielsen, 2011).

Both the coupled task (Gabbett et al., 2007; Hopwood et al., 2011; Williams et al., 2003) and uncoupled task (Abernethy et al., 2012; Gorman & Farrow, 2009; Lorains et al., 2013a; Murgia et al., 2014; Poulter et al., 2005; Ranganathan & Carlton, 2007) have resulted in significant performance gains from pre- to posttest in the laboratory using video simulations. Therefore, when perceptual-cognitive skills are trained in the laboratory, results have shown there is no difference between these types of tasks for both interceptive and invasion tasks.

3.4 **Speed of the videos**

When creating video simulation training, the effect of the speed of the videos has only been investigated by a few studies. These studies have revealed that expert athletes judge faster videos (1.25x and 1.5x actual speed) as closer to actual game speed (Lorains et al., 2013a; Lorains, Ball & MacMahon, 2013b). Furthermore, a follow-up study revealed that the increased speed of the videos led to quicker performance gains during training in the laboratory and better performance for the two week retention test (Lorains et al., 2013a). The authors believed that the participants, who were elite Australian football players, were forced to use higher levels of automaticity during the above real time videos, a contributing factor for higher decision-accuracy (Lorains et al., 2013a).

3.5 **Size of the screen**

When creating video simulation training, there is a great deal of variability regarding the size of the screen variable in the literature. Video simulation training uses screens that range from 17-inch laptops (Lorains et al., 2013a) to 1.83 m wide x 1.43 m high projections on the wall (Gorman & Farrow, 2009). The larger screens often result in life-size opponents and objects in the videos as well as larger head and saccade movements for the participants compared to the smaller laptop screens (Broadbent et al., 2015). Small computer screens (Abernethy et al., 2012; Lorains et al., 2013a; Murgia et al., 2014; Put, Wagemans, Jaspers & Helsen, 2013) as well as large projections on the wall (Gabbett et al., 2007; Gorman & Farrow, 2009; Hopwood et al., 2011; Poulter et al., 2005; Williams et al., 2003) have resulted in significant performance gains from pre- to posttest in the laboratory. Once again, results in the literature have shown there is no difference between the size of screens when training decision-making in the laboratory for both interceptive and invasion tasks.

3.6 **Viewing modality**

The final variable discussed will be the viewing modality used during video simulation training. The first category of viewing modality is the computer screen, which includes output devices such as laptop and/or desktop screens (Abernethy et al., 2012; Gorman & Farrow, 2009; Lorains et al., 2013a; Murgia et al., 2014; Put, Wagemans, Jaspers & Helsen, 2013), tablets (Casale, 2017) and projections on a wall/large screen (Gabbett et al., 2007; Hopwood et al., 2011; Poulter et al., 2005; Williams et al,. 2003). This modality allows athletes to train using randomized conditions and scenarios, allows athletes to train without requiring other athletes, facility access or cooperative weather for outdoor sports (Broadbent et al., 2015; Gray, in press; Miles, Pop, Watt, Lawrence & John, 2012). The computer screen modality has shown positive performance gains in the laboratory for both interceptive and invasion tasks and for several sports such as American football (Christina, Barresi & Shaffner, 1990), Australian football (Lorains et al., 2013a), basketball (Gorman & Farrow, 2009), cricket (Hopwood et al., 2011), soccer (Murgia et al., 2014; Poulter et al., 2005; Put et al., 2013), softball (Gabbett et al., 2007) and tennis (Broadbent, Causer, Ford & Williams, 2015; Williams et al., 2002).

The second category of viewing modality is virtual reality, which includes output devices such as interactive gaming systems such as the *Xbox, Wii, Playstation or Kinect* (Shin et al., 2016; Lee, Suh, Son, Kim, Eun & Yoon, 2016; Standen & Brown, 2017), interactive computer-simulated scenarios (Vignais et al., 2015) and Head Mounted Displays (HMD) (Bideau, Kulpa, Vignais, Brault, Multon & Craig, 2010; Casale, 2017; Kulpa, Multon & Argelaguet, 2015). For the purpose of this thesis, the emphasis within virtual reality will be placed on HMD virtual reality.

Since there is little empirical evidence demonstrating the effects of a HMD virtual reality video simulation training on decision-making in sports (Casale, 2017), the following section will discuss the potential advantages and disadvantages of this modality. The first advantage of HMD virtual reality is the level of immersion, which refers to the level to which the viewer believes he/she is physically present in the simulation (Gray, in press). HMD virtual reality provides the viewer with a level of immersion that is superior compared to the computer screen modality, a factor which has been suggested to be of paramount importance when studying perception and decision-making in sports (Craig, 2013; Zahorik & Jenison, 1998). The second advantage of HMD virtual reality is regarding the perception/action loop. In a real-life sporting event, an athlete will sample the information in the environment, using head and eye movements, to determine their decision for that given play. While watching a video simulation in HMD virtual reality, this modality increases the likelihood that the athlete will actively seek out the relevant information in a similar fashion to the real-life event. This information will be updated in real-time during the simulation as the athlete performs head movements in the HMD (Craig, 2013).

The first disadvantage of HMD virtual reality is regarding the possible side effects of this modality. It has been revealed that these simulations may cause dizziness, disorientation or nausea (Robert, Ballaz & Lemay, 2016; Salamin, Tadi, Blanke, Vexo & Thalmann, 2010). These side effects may discourage and event prevent certain users from training with this modality. The second disadvantage of HMD virtual reality is regarding the HMD device itself. These devices can be cumbersome to wear and reduce the effectiveness for users performing active tasks. Furthermore, wearing a HMD may reduce the level of immersion during the simulation as this device is not attached to their head during the real-life event (Craig, 2013; Miles et al., 2012).

As mentioned previously, there are some advantages and disadvantages of using HMD virtual reality over a computer screen modality. However, there is still limited empirical evidence comparing these two modalities.

3.7 **On court/field transfer**

The previous sections presented the effect of various variables on decision-making during video simulation training in the laboratory. The idea of transferring those performance gains to the field/court is considered the primary evaluation criteria when determining the effectiveness of the video simulation training program (Broadbent et al., 2015; Gray, in press). The upcoming sections will discuss how the variables mentioned previously affect transfer of performance gains. Furthermore, the sections will be separated into interceptive and invasion tasks.

Firstly, when assessing on-court/on-field transfer of an interceptive task, it is very difficult to determine which variables are more likely to result in positive transfer of performance gains. For example, studies have concluded that it is possible to obtain transfer of performance gains using the player's perspective (1st person) camera angle (Gabbett et al., 2007; Gray, 2017; Hopwood et al., 2011; Put et al., 2013, Williams et al., 2003), however no comparisons have been done to determine if this perspective is superior to the aerial camera angle. Similar issues are present, where variables are employed but not compared, for the type of response (Gabbett et al, 2007; Hopwood et al., 2011; Poulter et al., 2005; Williams et al., 2003), size of screen (Gabbett et al., 2007; Hopwood et al., 2011; Poulter et al., 2005) and viewing modality (Gabbett et al., 2007; Hopwood et al., 2011; Poulter et al., 2005, Williams et al., 2003). Finally, the speed of videos and HMD virtual-reality variables have yet to be investigated.

Secondly, when transfer is assessed following video simulation training of an invasion task, there is very little information on the effects each variable has on the transfer of performance gains. To date only two studies have investigated the effects of video simulations on the decision making skills on-court/on-field (Gorman & Farrow, 2009; Lorains et al., 2013a). The first study (Gorman & Farrow, 2009) showed no significant improvements in the on-court decision-making skills of their participants. The second study (Lorains et al., 2013a) did show significant transfer of performance gains; however the experiment was conducted during the participants' competitive season. Therefore, the improvements observed could have been driven by their regular on-field practices. With this in mind, it is still unclear how each variable affects the transfer of performance gains especially since video simulation training has yet to transfer to significant improvements on-court/on-field for an invasion task.

4. Objectives

When video simulation training is created for invasion tasks, it is still unclear what the most optimal combination of variables is to produce significant transfer of performance gains from the laboratory to the field/court. There are a few speculative reasons underlying the absence of conclusive evidence. Firstly, when transfer is assessed on-court/on-field, studies have evaluated decision-making using actual game footage of their participants before and after video simulation training. During competitive matches, the number of possible plays, both offensive and defensive, is quite substantial. As a consequence, in any given video simulation protocol, only a small fraction of all the possible plays can be presented. When transfer is assessed by observing participants' performance during regular games following the video training sessions (Gorman & Farrow, 2009), an absence of positive transfer may be caused by a difference in the pattern of plays observed in training and those faced when playing. In other words, video simulation may only lead to play-specific transfer. Furthermore, since only a small fraction of possible plays can be presented during video simulation training, the most optimal training method should include some generalization of learning from familiar situations (i.e., trained plays) to novel ones (i.e., untrained plays).

Therefore, the first objective of the current study was to determine whether video simulation training of an invasion task can lead to positive on-court transfer if the plays used to assess on-court transfer are similar (i.e., trained plays) and different (i.e., untrained plays) to those presented during training.

Alternatively, it is possible that the lack of transfer could be explained by the relatively modest level of immersion afforded by video simulations using a computer screen (PC or large projection), a factor that has been suggested as critical to video training sessions (Craig, 2013; Brault, Kulpa, Duliscouët, Marin & Bideau 2015; Gokeler et al., 2016; Lee et al., 2016).

Therefore, the second objective of the current project was to determine whether a decision-making training protocol using HMD virtual reality leads to superior on-field/on-court transfer compared to a computer screen viewing modality.

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Using video simulations and virtual reality to improve decision-making skills

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Running head: Video simulations and decision-making skills

ABSTRACT

A large body of literature supports the effectiveness of using video simulations to improve decision-making skills in invasion tasks. However, whether these improvements are transferable (from the laboratory to the court/field) and generalizable (from trained to untrained plays) remains unknown. In addition, it remains to be determined whether presenting the video simulations using virtual reality provides an added-value. To investigate these questions, varsity-level basketball players underwent four training sessions during which they observed video clips of basketball plays presented either on a computer screen (CS group) or using a virtual reality headset (VR group). A third group watched footage from NCAA playoff games on a computer screen (CTRL group). Decision-making was assessed on-court before and after the training sessions using two types of plays: "trained" plays (presented during the CS and VR training sessions) and "untrained" plays (presented only during the on-court tests). When facing the trained plays in the posttest, both VR and CS groups significantly outperformed the CTRL group. In contrast, when facing the untrained plays, the VR group outperformed both the CS and CTRL groups. Our results indicate that CS training leads to transferable but non-generalized decision-making gains while VR training leads to transferable and generalized gains.

Keywords: Decision-making, video simulation training, virtual reality, learning transfer, learning generalization

Introduction

In sporting events, expert performance is often associated with the execution of accurate and consistent movements. In many team sports however, it is also equally important for athletes to efficiently process the surrounding information to select the most appropriate action in a given situation (North, Williams, Hodges, Ward, & Ericsson, 2009; Williams & Ericsson, 2005; Williams, Ward, & Chapman, 2003). Consequently, training decision-making skills must be part of all sound training programs. Since the pioneering work of Fitts and Posner (1967) on the power law of practice to the more contemporary theories on deliberate practice (Ericson, Krampe, & Tesch-Römer, 1993) and deliberate play (Côté, Baker, & Abernethy, 2003), it is now well established that physical practice plays a crucial role in the development of all facets of expertise. Yet, alternative training methods may sometimes be required when physical practice is impractical or even impossible (e.g., when the availability of training facilities or partners is limited, when recovering from an injury, etc.). Perhaps the most popular alternative to train decision-making skills in team sports is the use of video simulations in which athletes watch video replays of their previous performances and/or of games played by professionals. Through these video simulations, it is believed that athletes learn to identify relevant visual cues and/or recognize specific patterns of play and use this knowledge to select the most appropriate action when facing a similar situation in “real life.”

Recently, the effectiveness of this training modality has been the subject of substantial investigation (see Broadbent, Causer, Williams, & Ford, 2015; Cotterill & Discombe, 2016, for reviews). In typical experiments, participants are presented with video clips (either on a computer/TV screen or projected on a wall) of professional-level games and asked to immerse themselves vicariously in the action. At different moments, the experimenter stops the video and asks participants to identify the action they would perform if they were playing. With practice and feedback, participants usually improve and learn to select optimal actions in the laboratory (Gorman & Farrow, 2009; Hohmann, Obelöer, Schlapkohl, & Raab, 2016; Lorains et al., 2013). However, these improvements have not been associated with convincing evidence of positive transfer when performance is later assessed on the field/court (Broadbent et al., 2015; Cotterill & Discombe, 2016; Loffing, Hagemann, & Farrow, 2017). One possibility that could account for this lack of transfer is the substantial number of possible plays, both offensive and defensive, that can occur in team sports. As a consequence, in video simulation training, only a small fraction of all possible plays can be presented. When transfer is assessed by observing participants' performance during regular games following the video training sessions (Gorman & Farrow, 2009), an absence of positive transfer may be caused by a difference in the patterns of play observed in training and those faced when playing. In other words, video simulation may only lead to play-specific transfer and may not generalize to untrained patterns of play. Alternatively, the lack of positive transfer can be explained by the relatively modest level of immersion afforded by video simulations using a TV/computer screen, a factor that has been suggested as critical to effective video training (Brault, Kulpa, Duliscouët, Marin, & Bideau 2015; Craig, 2013; Gokeler et al., 2016; Jungjin & BumChul, 2016). In this regard, it is noteworthy that modern technology can now afford viewers with an enhanced sense of immersion in the action. In particular, several media now use "virtual reality" technology to present videos in which the viewers can see the full 360-degree scene around the camera simply by wearing a head mounted display (HMD) that adjusts the image in real time based on the orientation of the viewer's head. In a sporting context, recent reports have demonstrated the effectiveness of virtual reality to improve various skills when performance is assessed in the laboratory (Casale, 2017; Correia, Araújo, Cummins, & Craig, 2012; Cortes, Blount, Ringleb, & Onate, 2011; Miles, Pop, Watt, Lawrence, & John, 2012). However, none of them tested the transferability of the gains from the laboratory to the field.

Therefore, the objectives of the current project were to determine whether a decision-making training protocol using a computer screen viewing modality can lead to transferable (from the laboratory to the court/field) and generalizable (from trained to untrained patterns of play) gains in decision-making skills and whether a virtual reality viewing modality provides an added-value.

Methodology

Participants

Twenty-seven basketball players (21 men and 6 women) were recruited for this project. They were aged between 16 and 26 year-old (M = 19.4 years, SD = 3.7), were playing at a varsity level (highest level at their academic institution), and had been playing basketball for an average of 7.0 years (SD = 1.7). They were randomly divided into three equal groups, hereafter referred to as the Virtual reality (VR), Computer screen (CS), and Control (CTRL) groups. All experimental sessions were conducted during the participants' off-season; they therefore did not take part in any team practices during the study. The study was approved by the Research Ethics Board of Bishop's University.

Equipment

Videos for the training sessions of the VR and CS groups were custom-made for this research project and acquired using a *Ricoh Theta S* 360° camera and a *GoPro Hero 3*, respectively. The *GoPro Hero 3* captured 123° horizontally and 94° vertically while the *Ricoh Theta S* captured everything around it (horizontally and vertically) with the exception of a small area directly underneath the camera. Videos for the VR group were edited with *Final Cut Pro* (Apple Inc.) while *iMovie* (Appel Inc.) was used to edit videos for the CS group. Participants assigned to the VR group watched the virtual reality videos using a *Utopia 360* Head Mounted Display (HMD) equipped with an LG3 smartphone (LG Electronics) while an *iMac* desktop computer (iMac14.1, 21.5-inch) was used to present videos for the CS and CTRL groups. The HMD presented 110° horizontally and 100° vertically of the original scene (with both components being adjusted in real time based on the orientation of the participant's head) while the computer screen displayed the entire field of view recorded with the *GoPro Hero 3*.

Procedures

All experimental sessions took place over a period of seven days. An on-court pretest was performed on Day 1 followed by four training sessions scheduled between Days 2 and 6 (no more than one session per day). Finally, an on-court posttest was performed on Day 7.

Video training sessions

During the week following the on-court pretest, participants of the VR, CS, and CTRL groups took part in four off-court training sessions. During these sessions, participants assigned to the VR and CS groups observed custom-made videos showing, from a first person perspective, nine actors (four of them playing the role of "teammates" and five acting as "opponents") performing pre-determined variations of two distinct offensive patterns of basketball play (see Figure 1 for a representative screenshot). These videos were acquired prior to the beginning of the experimental phase of the study using the *Ricoh Theta S* and *GoPro Hero 3* positioned one above the other. Thus, from an observer's point of view, the perspective of the images captured by both cameras was identical and the same plays were presented to participants of the VR and CS groups. The video clips averaged 14.7 seconds (*SD* = 0.2) and a total of 120 different video clips were recorded.

The experimental procedures were identical for both the VR and CS groups during the training sessions with the exception of a short familiarization phase with the HDM which was provided to participants of the VR group. More specifically, at the beginning of each training, VR participants watched a 2-minute clip of an underwater documentary to familiarize themselves with the virtual reality and 360° environment; such a session has been shown to reduce the likelihood of experiencing negative symptoms associated with virtual reality such as dizziness and nausea (Carnegie et Rhee, 2015).

During each training session, participants of the VR and CS groups observed 50 video clips (10 additional familiarization videos were presented at the beginning of the first session; these trials were not included in the analyses) for a weekly total of 200 video clips. Of these 200 clips, 80 were presented twice during the week while 40 clips were presented only once. The order of the clips was randomized but identical for all participants. At the end of each clip, participants were asked to answer verbally the following question: "Where would you move to best help your team succeed in scoring a basket?" The four possible options were: move left, right, forward, or stay put. To control for a possible speed-accuracy trade-off in decision-making, the participants' response had to be given within a fixed time period (see Figure 2a). More specifically, at a specific moment during each video clip (on average 8 seconds after the beginning of the clip), participants heard a first auditory signal indicating that they would soon have to give their answer. Exactly two seconds after the first auditory signal, the video clip was temporarily occluded and the screen became black. This occlusion served as the cue signal prompting participants to verbally mention to the experimenter their selected action. One second after the screen occlusion, a second auditory signal was generated to indicate the end of the response period; any answer given after this time was considered erroneous. One second after the final auditory signal, a screenshot of the final video frame seen before the occlusion was presented for 2.5 seconds along with the word indicating the "best" answer for that trial. To evaluate the participants' decision-making accuracy, a three-point scoring system was created. Two points were awarded if the participant selected the "best" action, one point was given for the two actions deemed as "acceptable", and zero point was awarded for the "worst" action, if no action was mentioned, or if the action was mentioned after the third auditory signal**.** To identify which action could be considered "best", "acceptable", or "worst", three varsity level basketball coaches in the Sherbrooke area reviewed individually all the video clips and were asked to rank the four possible actions. Only plays for which the ranking was unanimous among the coaches were kept for the training sessions. The decision-making accuracy score of each participant was calculated by adding all the points obtained during each session and dividing it by the maximum possible score.

Participants assigned to the CTRL group were invited to come to the laboratory four times during the week following the on-court pretest to watch on a computer screen a 15-minute video showing a university-level basketball game (NCAA). This duration was similar to the length of the training sessions of the VR and CS groups. The videos were different during each session and were taken from four different games. All participants observed the same videos.

On-court pretest and posttest

To assess the transferability of the decision-making gains resulting from the video training sessions, all participants were invited to perform two on-court tests on a regular-size basketball court in an indoor gymnasium. Upon arrival to the gymnasium, participants performed a 5-minute dynamic warm-up session similar to those performed prior to regular basketball practices (i.e., dynamic movements of the upper and lower body, low to medium intensity running, shooting) and were then given verbal instructions regarding the on-court test. During the testing phase, participants were asked to observe nine actors (four of them playing the role of "teammates" and five acting as "opponents") perform 21 pre-determined basketball plays. At the end of each play, participants were asked to move to a location on the court that would best help their team score points. As in the training sessions, four different responses were possible: move left, right, forward, or stay put. Each trial followed the same sequence of events (see Figure 2b). First, the participant was placed by the experimenter at a specific location on the basketball court and was asked to observe the actors perform the play. At a pre-determined moment during the play (that is, when one of the offensive "teammate" performed a specific action; on average eight seconds into the play), the experimenter initiated a sequence of three pre-recorded auditory signals (emitted using 2 *Logitech V10 USB* speakers). The first auditory signal served as a pre-cue signal instructing the participant that a response (i.e., movement) would be required shortly. Exactly two seconds after the first signal, a second auditory signal was generated prompting the participant to perform his/her action (go-cue). Finally, a third auditory signal was generated one second later and marked the end of the trial. Any action initiated after the third auditory signal was considered erroneous. All on-court tests were recorded using a *Canon XF400 4K* camcorder to calculate the participants' decision-making score *post hoc*.

To assess the generalization of the decision-making gains, two types of play were used during the on-court tests (hereafter named "Trained" and "Untrained" plays). The Trained plays consisted in minute variations of the same two patterns of plays that were repeatedly presented to the participants during the training sessions. In contrast, the Untrained plays consisted of minute variations of a third and distinct offensive pattern of play which shared no similarity with the Trained plays and which had not been presented during the training sessions. These two types of plays (Trained and Untrained) were randomly distributed in the pretests and posttests but their order was identical for all participants. In both the pretests and posttests, the first three trials served as familiarization and were not included in the analyses. The participants' decision-making accuracy was therefore evaluated on the remaining 18 plays (12 Trained and 6 Untrained plays). The same plays were presented in the pretest and posttest, albeit in a different order.

The participant's decision-making accuracy score was calculated in the same way as in the training sessions. In addition, the three coaches who assessed the video clips were individually presented sketches of the pre-determined plays and were asked to rank the four options. Only plays for which there was no disagreement between the coaches were used.

Data analysis

To assess whether the training sessions allowed participants of the VR and CS groups to improve their decision-making skills in the laboratory, the participants' score for each training session were compared using a 2 Groups x 4 Sessions ANOVA with repeated measures on the second factor. To assess whether the training sessions led to any on-court transfer gains, a 3

Groups x 2 Tests x 2 Types of play ANOVA with repeated measurements on the last two factors was computed using the decision-making accuracy scores of the pretest and posttest. The ANOVA assumptions were first verified and post hoc pairwise comparisons were computed with a Bonferroni correction, when needed. All significant effects are reported at $p < 0.05$ and the p values indicated in the Results section represent the adjusted values.

Results

Training sessions

To determine if the training sessions allowed participants to improve their decision-making skills in the laboratory, we first compared the participants' decision-making accuracy scores using a 2 Groups (VR x CS) x 4 Sessions ANOVA. The ANOVA revealed no significant main effect of Group $F(1,16) = 1.27$, $p = 0.27$, $\eta^2_p = 0.07$, nor a Group x Session interaction $F(3,48) = 1.01$, $p = 0.4$, $\eta^2_p = 0.06$. However, the ANOVA did reveal a significant main effect of Session, $F(3, 48) = 43.12$, $p < 0.001$, $\eta^2_p = 0.73$. Post hoc comparisons revealed that participants significantly improved from sessions 1 to 3 ($p < 0.001$), 1 to 4 ($p < 0.001$), 2 to 3 ($p = 0.006$), 2 to 4 ($p < 0.001$), and 3 to 4 ($p = 0.004$; see Figure 3).

On-court transfer

To determine whether the improvement observed in the laboratory resulted in positive on-court transfer, we computed a 3 Groups (VR x CS x CTRL) x 2 Tests (Pre x Post) x 2 Types of play (Trained vs Untrained) ANOVA. The ANOVA revealed a significant Group x Test x Type of play interaction, $F(2, 24) = 47.9$, $p < 0.001$, $\eta^2_p = 0.8$. This interaction was broken down by computing a separate Group x Test ANOVA for each Type of play.

For the Trained plays, the ANOVA revealed a significant main effect of Group, $F(2, 32) = 9.41$, $p = 0.001$, $\eta^2_p = 0.37$, a significant main effect of Test, $F(1, 16) = 39.6$, $p < 0.001$, $\eta^2_p = 0.71$, and a significant Group x Test interaction, $F(1, 16) = 18.3$, $p = 0.001$, $\eta^2_p = 0.53$. As illustrated on Figure 4a, post hoc comparisons revealed no significant difference between the groups in the pretest (all $p = 1$). In the posttest, participants in the VR and CS groups significantly outperformed those in the CTRL group (mean decision-making accuracy scores of 79.0%, 73.2% and 57.5%, respectively; $p \leq 0.01$). No significant difference was found between the VR and CS groups ($p = 0.21$).

For the Untrained plays, the ANOVA revealed no significant main effect of Group, $F(2, 32) = 3.26$, $p = 0.05$, $\eta^2_p = 0.17$. However, the ANOVA revealed a significant main effect of Test, $F(1, 16) = 9.52$, $p = 0.007$, $\eta^2_p = 0.37$, and a significant Group x Test interaction, $F(1, 16) = 13.76$, $p = 0.002$, $\eta^2_p = 0.46$. As illustrated on Figure 4b, post hoc comparisons revealed no significant difference between the groups in the pretest (all $p > 0.9$). In the posttest, participants in the VR group significantly outperformed those in the CS and CTRL groups (mean decision-making accuracy scores of 78.9%, 60.9% and 60.2%, respectively; $p \leq 0.002$). However, no significant difference was found between the CTRL and CS groups ($p = 1$).

Discussion

This study investigated whether a training program using video simulations can lead to transferable (from the laboratory to the court) and generalized (from trained to untrained plays) gains in decision-making skills. Our results revealed that using a computer screen presentation modality resulted in transferable but non-generalized gains while the same videos presented using virtual reality resulted in transferable and generalized gains.

Our observation that the gains in decision-making skills obtained through a video simulation training program transfer to a real-life context (i.e., a basketball court) provides a much needed extension of previous works which reported improvement only in the laboratory (see for example Broadbent et al., 2015; Gray, in press, for discussions on the topic). While compelling evidence existed to support the effectiveness of using video simulations to improve anticipation skills in interceptive tasks like baseball/softball (Gabbett, Rubinoff, Thorburn, & Farrow, 2007; Gray, 2017), tennis (Williams, Ward, Knowles, Smeeton, 2002), and cricket (Hopwood, Mann, Farrow, & Nielsen, 2011), previous studies investigating decision-making skills in invasion tasks either did not assess on-court/field transfer or had methodological issues preventing the formulation of definitive conclusions. For example, Gorman and Farrow (2009) assessed transfer by evaluating the quality of their participants' decisions during their regular games following the training program. Since participants were likely to face during their regular games patterns of play different than those observed during the video simulation training, the authors not only assessed the transferability of the gains but also their generalization. In light of our results revealing that improvements are play-specific when using the CS presentation modality, it is not surprising they reported no significant gains. Similarly, Lorains et al. (2013)

reported that a video-based training program allowed elite Australian football players to demonstrate significant improvement in their decision-making skills during a regular game. However, since the experiment was conducted during the players' regular season, this improvement could have simply been driven by their regular on-field practices (a possibility further reinforced by the observation that their control group improved as much as their trained groups). Thus, our results add to previous ones by demonstrating the effectiveness of video simulations to improve athletes' on-court/field decision-making skills.

It is also exciting to note the VR presentation modality led to superior on-court improvement compared to the CS modality, even if the training videos used were similar (same plays, same viewing perspective, same number of clips, etc.). More specifically, only VR resulted in decision-making gains that generalized to untrained plays. This difference between CS and VR may be related to the two major criticisms that have been formulated regarding the use of video simulations: 1) the relatively modest level of immersion afforded by projections using computer/TV screen (Craig, 2013; Brault et al., 2015; Gokeler et al., 2016; Jungjin & BumChul, 2016) as well as 2) the decoupling between the acquisition of the visual information and the production of movement (Craig, 2013, Gray, in press). In our VR condition, videos were presented using an HMD that was responsive to the movements of the head. While the coupling between observation and action was relatively modest (and limited to the movements of the head), the level of immersion in the VR condition was undoubtedly enhanced as HMD made it impossible for participants to view the surrounding laboratory environment, thus helping them "believe" they were on the basketball court. Thus, our results provide support for the notion that enhanced immersion is important to maximize the benefits of video simulation training.

From a mechanistic point of view, the reason why the CS and VR conditions led to different generalization results is intriguing. Seminal work has suggested that, in a sporting context, decision-making relies on the integration of sensory information acquired during the action (e.g., movements of the opponents) with existing knowledge stored in long-term memory (e.g., known patterns of play) (Marteniuk, 1976). Expertise is therefore a function of one's capacity to acquire the relevant sensory information during the action and the extent of one's prior knowledge. In support of this model, it has been shown that experts are able to use vision more effectively and efficiently than novices to scan the environment and extract relevant information (Broadbent et al., 2015). For example, experts are better at picking up perceptual cues and require fewer visual fixations to extract the relevant information (see Mann, Williams, Ward, & Janelle, 2007, for a meta-analysis). Additionally, it has been demonstrated that experts are better at utilizing prior knowledge to anticipate the movements of their opponents (Abernethy, Gill, Parks, & Packer, 2001). Based on this model, it is possible that the CS condition allowed participants to increase their repertoire of known patterns of play (i.e., prior knowledge). By being repeatedly confronted to variations of the same two plays in training, participants became better attuned to their specific characteristics, making it easier for them to recognize the plays during the on-court posttest. However, because the knowledge developed was play-specific, it led to no advantage when facing the new and untrained play. In contrast, the VR condition may have led to improvement in the participants' capacity to search and acquire relevant visual information. This hypothesis is supported by a prior report which demonstrated that individuals adopt different visual search behavior when looking at 2D vs 3D videos (Lee, Tidman, Lay, Bourke, Lloyd, & Alderson, 2013). Although our VR condition was not presented in pure 3D, it nevertheless allowed participants to actively select which portion of the full 360-

degree scene they wanted to look at as the image displayed in the HMD was determined by their head orientation. This may have encouraged participants to become more active information seekers (Craig, 2013) and to direct their attention to the information-rich areas of the display (Mann et al., 2007), thus possibly leading them to improve implicitly how they acquire visual information (Jackson & Farrow, 2005). This would result in decision-making gains that are not specific to certain patterns of play but applicable to all situations encountered on the court. Further experiments will however be required to confirm these hypotheses.

In conclusion, our results support the effectiveness of using video simulations to improve decision-making skills of athletes and confirm the value of this training modality when physical practice is limited or impossible. In addition, the superior gains obtained with virtual reality simulation combined with the enhanced accessibility of this technology make it a very appealing strategy to further optimize the development of athletes.

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Declaration of interest

No conflicts of interest, financial or otherwise, are declared by the authors.

References

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception*, *30*(2), 233-252.

Brault, S., Kulpa, R., Duliscouët, L., Marin, A., & Bideau, B. (2015). Virtual Kicker vs. real goalkeeper in soccer : a way to explore goalkeeper's performance. *Movement & Sport Sciences*, (3), 79-88.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European Journal of Sport Science*, *15*(4), 322-331.

Carnegie, K., & Rhee, T. (2015). Reducing visual discomfort with HMDs using dynamic depth of field. *IEEE computer graphics and applications*, *35*(5), 34-41.

Casale, M. (2017). STRIVR Training Demonstrates Faster and More Accurate Learning Compared to Traditional Study Methods.

Correia, V., Araújo, D., Cummins, A., & Craig, C. M. (2012). Perceiving and acting upon spaces in a VR rugby task: expertise effects in affordance detection and task achievement. *Journal of Sport and Exercise Psychology*, *34*(3), 305-321.

Cortes, N., Blount, E., Ringleb, S., & Onate, J. A. (2011). Soccer-specific video simulation for improving movement assessment. *Sports biomechanics*, *10*(01), 22-34.

Côté, J., Baker, J., & Abernethy, B. (2003). From play to practice. *Expert performance in sports: Advances in research on sport expertise. United State: Human Kinetics*, 89-113.

Cotterill, S., & Discombe, R. (2016). Enhancing decision-making during sports performance: Current understanding and future directions. *Sport and Exercise Psychology Review*, *12*, 54-68.

Craig, C. (2013). Understanding perception and action in sport: how can virtual reality technology help?. *Sports Technology*, *6*(4), 161-169.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological review*, *100*(3), 363-406.

Fitts, P. M., & Posner, M.I. (1967). Human performance. Oxford, England: Brooks/Cole

Gabbett, T., Rubinoff, M., Thorburn, L., & Farrow, D. (2007). Testing and training anticipation skills in softball fielders. *International Journal of Sports Science & Coaching*, *2*(1), 15-24.

Gorman, A. D., & Farrow, D. (2009). Perceptual training using explicit and implicit instructional techniques: Does it benefit skilled performers?. *International Journal of Sports Science & Coaching*, *4*(2), 193-208.

Gokeler, A., Bisschop, M., Myer, G. D., Benjaminse, A., Dijkstra, P. U., van Keeken, H. G.,…Otten, E. (2016). Immersive virtual reality improves movement patterns in patients after ACL reconstruction: implications for enhanced criteria-based return-to-sport rehabilitation. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(7), 2280-2286.

Gray, R. (2017). Transfer of Training from Virtual to Real Baseball Batting. *Frontiers in psychology*, *8*, 2183.

Gray, R. (in press). Virtual environments and their role in developing and understanding perceptual-cognitive skills. In A.M. Williams & R. Jackson (Eds). *Anticipation and Decision Making in Sport*.

Hohmann, T., Obelöer, H., Schlapkohl, N., & Raab, M. (2016). Does training with 3D videos improve decision-making in team invasion sports?. *Journal of sports sciences*, *34*(8), 746-755.

Hopwood, M. J., Mann, D. L., Farrow, D., & Nielsen, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers?. *International Journal of Sports Science & Coaching*, *6*(4), 523-535.

Jackson, R. C., & Farrow, D. (2005). Implicit perceptual training: How, when, and why?. *Human Movement Science*, *24*(3), 308-325.

Jungjin Kim PT, M. S., & BumChul Yoon, P. T. (2016). Patient perspectives on virtual reality-based rehabilitation after knee surgery: Importance of level of difficulty. *Journal of rehabilitation research and development*, *53*(2), 239.

Lee, M. J., Tidman, S. J., Lay, B. S., Bourke, P. D., Lloyd, D. G., & Alderson, J. A. (2013). Visual search differs but not reaction time when intercepting a 3D versus 2D videoed opponent. *Journal of motor behavior*, *45*(2), 107-115.

Loffing, F., Hagemann, N., & Farrow, D. (2017). The next piece of the puzzle. In J. Baker, S. Cobley, J. Schorer, & N. Wattie (Eds.), *Routledge Handbook of Talent Identification and Development in Sport* (pp. 205-218). London, Routledge.

Lorains, M., Ball, K., & MacMahon, C. (2013). An above real time training intervention for sport decision making. *Psychology of Sport and Exercise*, *14*(5), 670-674.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *29*(4), 457-478.

Marteniuk, R. G. (1976). Cognitive information processes in motor short-term memory and movement production. In *Motor control* (pp. 175-186).

Miles, H. C., Pop, S. H., Watt, S. J., Lawrence, G. P. & John, N. W. (2012). A review of virtual environments for training in ball sports. *Computers & Graphics, 36*, 714-726.

North, J. S., Williams, A. M., Hodges, N., Ward, P., & Ericsson, K. A. (2009). Perceiving patterns in dynamic action sequences: Investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology*, *23*(6), 878-894.

Williams, A. M., & Ericsson, K. A. (2005). Perceptual-cognitive expertise in sport: Some considerations when applying the expert performance approach. *Human movement science*, *24*(3), 283-307.

Williams, A. M., Ward, P., & Chapman, C. (2003). Training perceptual skill in field hockey: Is there transfer from the laboratory to the field?. *Research quarterly for exercise and sport*, *74*(1), 98-103.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied*, *8*(4), 259-270.

Figure captions

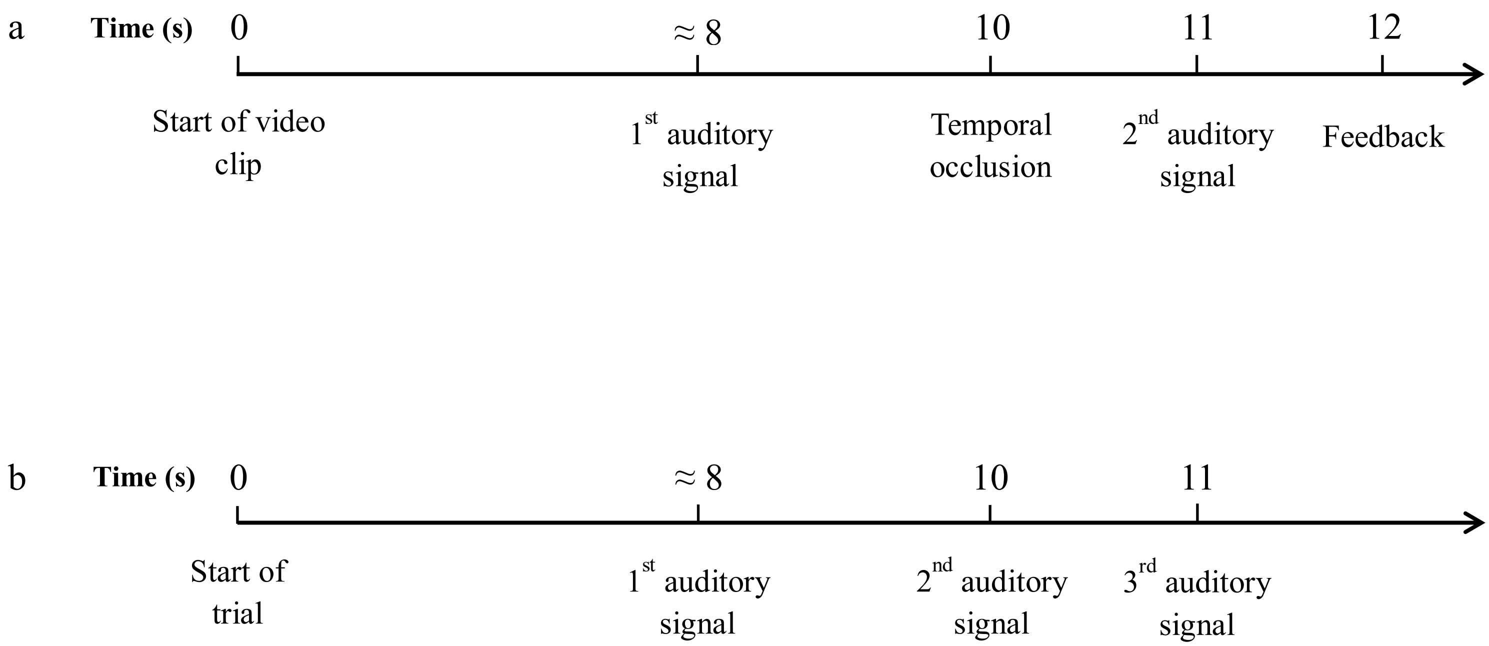
Figure 1 - Screenshot of one of the videos used during the training sessions (computer screen modality).

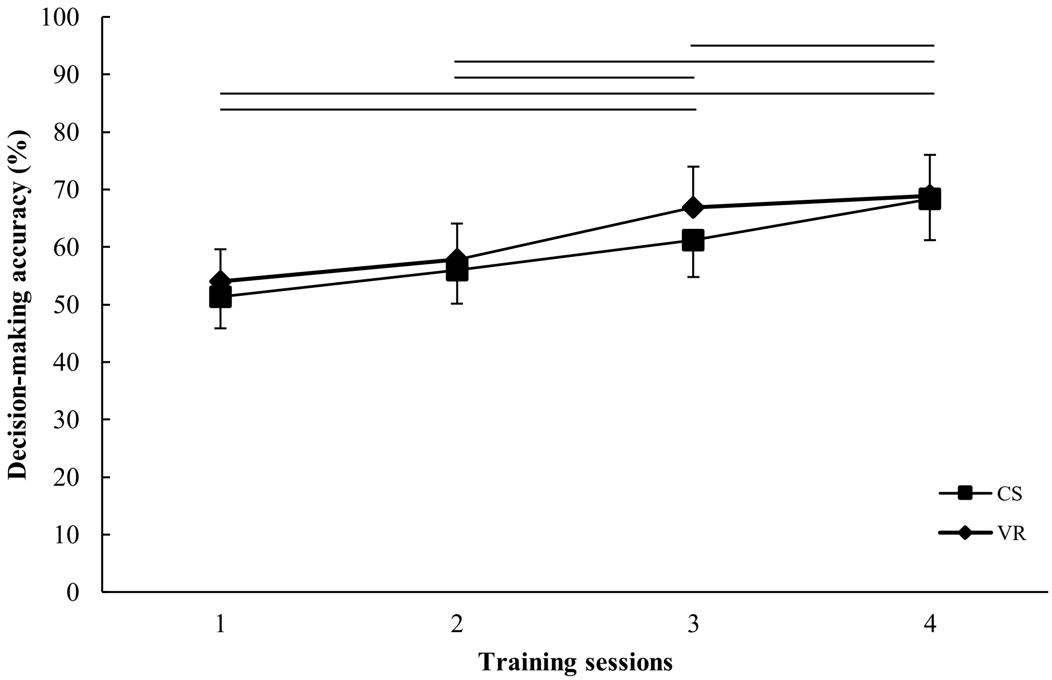
Figure 2 - Timeline of a trial during the training sessions (a) and on-court tests (b). For the training sessions, the first auditory signal represented the pre-cue, the temporal occlusion represented the beginning of response time, and the second auditory signal represented the end of response time. For the on-court tests, the first auditory signal represented the pre-cue, the second represented the go-cue, and the third represented the end of the response time.

Figure 3 - Mean decision accuracy scores of the CS and VR groups during the training sessions. The horizontal bars indicate a significant difference between sessions and error bars illustrate *SEM*.

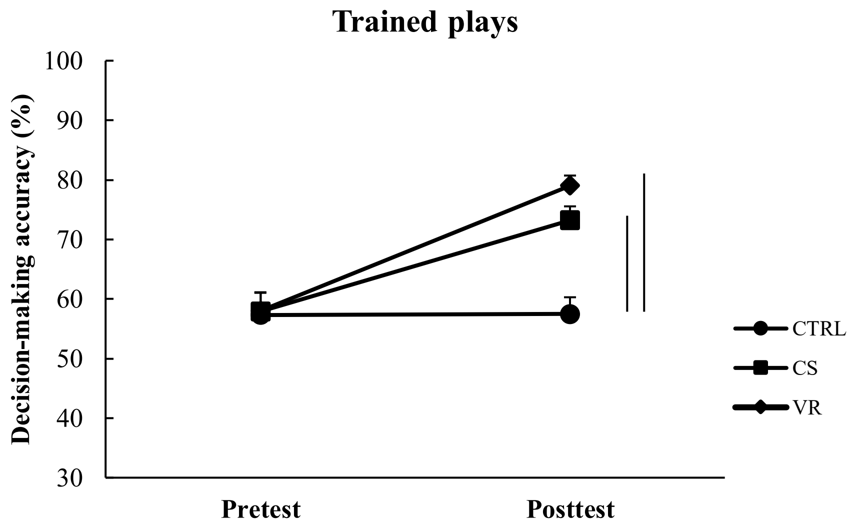
Figure 4 - Mean decision accuracy scores for the Trained (a) and Untrained (b) plays during the pre- and posttest. The vertical lines indicate a significant difference between groups and error bars illustrate *SEM*.

Figures


a
Time (s)
0
≈ 8
10
11
12
Start of video clip
1st auditory signal
Temporal occlusion
2nd auditory signal
Feedback
b
Time (s)
0
≈ 8
10
11
Start of trial
1st auditory signal
2nd auditory signal
3rd auditory signal

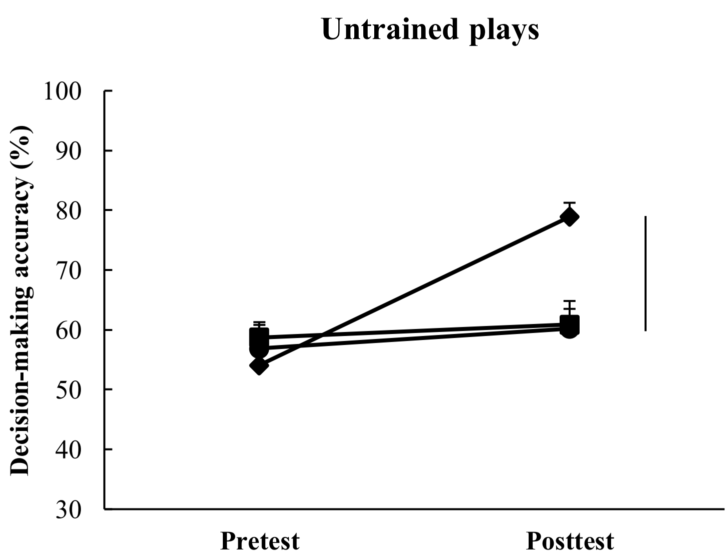

100
90
80
70
60
50
40
30
20
10
0
Decision-making accuracy (%)
CS
VR
1
2
3
4
Training sessions

a



Trained plays
Decision-making accuracy (%)
100
90
80
70
60
50
40
30
Pretest
Posttest
CTRL
CS
VR

b



Untrained plays
Decision-making accuracy (%)
100
90
80
70
60
50
40
30
Pretest
Posttest

6. Discussion

The first objective of the current thesis was to determine whether video simulation training of an invasion task, using a computer screen, can lead to positive and generalized on-court transfer. The second objective of the current thesis was to determine whether video simulation training using HMD virtual reality leads to superior on-field/on-court transfer compared to the computer screen viewing modality.

6.1 **Virtual reality vs computer screen**

This study revealed significant transfer of performance gains from the laboratory to the court for both the computer screen and virtual-reality modalities, with the latter producing superior transfer due to the generalization of learning to novel situations. The upcoming section will compare the two viewing modalities using the evaluation criteria proposed by Gray (2018) which include physical and psychological fidelity as well as technical specifications.

Firstly, physical fidelity is defined as "the extent to which the simulation looks, feels and sounds like the real environment" (Gray, in press). It is also believed that higher physical fidelity results in more accurate information sampling closer to the sampling which occurs in real life. Therefore, the specificity of practice principle is more closely implemented in higher physical fidelity. It is noteworthy, however, that this speculation is possible as long as there are not any distortions or lags of the perceptual information due to high quality graphics (Gray, in press). In the current study, both training modalities had identical sounds; however the differences between the simulations were in the visual information sampling and how the VR group had control over the field of view during viewing. Users in the computer screen modality viewed scenarios from a fixed viewpoint with no opportunities to change the angle of the field of view. Users in the virtual-reality modality also viewed scenarios from a fixed viewpoint; however these participants were able to change the angle of their field of view similarly to a real-life experience. Therefore, visual information was updated in real time based on the viewer's head orientation in the laboratory environment resulting in higher physical fidelity (Craig, 2013). We speculate that this higher physical fidelity resulted in participants improving their search behavior regarding the "when" and the "where" to pick up the crucial pieces of information (Jackson & Farrow, 2005) whereas participants in the computer screen group developed their pattern recognition skills and a "look up table" in order to retrieve the answer to the recognized pattern of play over time. We also speculate that this improved search behavior in the VR group is a driving force in the generalization of learning observed in the HMD virtual reality group. We believe that participants in this group were able to apply what they learned during the training sessions regarding the "what" and "where" to focus their gaze to the novel plays observed in the posttest. Furthermore, we speculate that this improved search behavior may have allowed participants to acquire information regarding perceptual invariants, referring to perceptual information linked to the task that remains constant despite other information sources changing (Farrow, 2013). Learning perceptual invariants has been suggested to lead to better transfer than learning the overall differences between the patterns (Craig, 2013; Farrow, 2013; Holden, 2005; Lintern, 1991).

Secondly, psychological fidelity is defined as "the extent to which the simulation recreates the perceptual-cognitive demands of the real task and leads to similar behaviors being observed from the user as in the real environment" (Miller, 1954; Gray, in press). In the current study, both training modalities had very low psychological fidelity as none of the participants performed any of the physical responses. Participants remained seated during all the training sessions to avoid any negative physiological side-effects. However, this low psychological fidelity did not prevent participants from significantly improving their decision accuracy on the court following the training regimen which goes against a speculation advanced by Gray in his review in 2018 stating "Given the evidence of specificity of practice it is likely that psychological fidelity is more strongly related to transfer of training than physical fidelity" (Gray, in press). Our results therefore suggest that high psychological fidelity is not required to obtain significant transfer of performance gains.

The final evaluation criteria involve technical specifications for video simulations include the use of stereoscopic displays as well as the size of the field of view. Stereoscopic displays result in a more realistic environment which usually results in higher immersion. However, this technology can result in negative physiological side-effects such as eye fatigue and discomfort, dizziness and nausea**.** Furthermore, stereoscopic images often result in temporal lags and a reduced frame rate (see Miles et al., 2012, for a review**)**. In the current study, stereoscopic images were not used as part of the training program; this did not prevent participants from improving their on-court decision-making accuracy. Our results therefore suggest that stereoscopic images are not required to improve decision-making skills on the court/field.

Furthermore, the technical specification also includes the field of view of the viewing modality. The size of the field of view is a characteristic based on the type of camera used to acquire footage (i.e., *GoPro* wide angle lens vs *GoPro* narrow angle lens). This characteristic is distinct from the relative size of the screen which is obtained by measuring the size of a given object in the display (i.e., the height of a basketball player in the screen) and the distance from the screen to the retina. For a given field of view, the relative size of the screen and the objects within the screen vary based on individuals' distance to the screen, whereas the field of view is an absolute measure based on the characteristics of the camera used. With this in mind, it has been suggested that athletes use mainly their central and/or near peripheral vision for decision-making (Ryu, Abernethy, Mann, Poolton & Gorman, 2013). Therefore, additional peripheral information may not be required to provide transfer of performance gains, which would suggest that a narrow field of view is sufficient to improve decision-making performance. In the current study, the field of view at any given moment was larger for the computer screen modality than for the virtual reality modality (see Methodology for details). The results of the current study revealed that the smaller field of view led to superior transfer of performance gains compared to the larger field of view.

6.2 **Video simulation variables**

As mentioned in the introduction, there are several key variables to consider when creating video simulation training (more specifically, the camera angle, the type of response required from the participants, the speed of the videos, the size of the screen, and the viewing modality). The upcoming section will compare the current study to the literature as well as what the results of the current study teach us regarding decision-making skills, and this for each variable.

As mentioned previously, the literature has shown inconclusive results when using an aerial view camera angle (Gorman & Farrow, 2009; Lorains et al., 2013a). However, when investigating invasion tasks, the effectiveness of the player's perspective has yet to be investigated which is why the current study used a player's perspective camera angle during training. The results of the current study revealed that the player's perspective camera angle led to positive transfer of performance gains for both the CS and VR viewing modalities. Since the transfer of performance gains using the player's perspective camera angle during an invasion task is a novel result, we expanded our comparison with the literature to include studies investigating interceptive tasks. Our results are similar to several studies investigating interceptive tasks (Gabbett et al., 2007; Gray, 2017; Hopwood et al., 2011; Put et al., 2013, Williams et al., 2003). The current study did not include any comparison between camera angles; we therefore cannot determine which camera angle results in the best transfer of performance gains, but our results do contribute to the effectiveness of using a player's perspective camera angle for an invasion task.

Furthermore, as mentioned previously, the literature has shown no difference between requiring participants to respond using a coupled or an uncoupled task, which puts into question the importance of psychological fidelity. Performing movements while using HMD virtual reality has resulted in negative side effects such as dizziness and nausea (Carnegie & Rhee, 2015; Dziuda, Biernacki, Baran & Truszczynski, 2014). Therefore, to increase the safety and well-being of participants during HMD virtual reality, we decided to use an uncoupled task for all experimental conditions. The results of the current study revealed that an uncoupled task led to positive transfer of performance gains for both viewing modalities. Our results are similar to the decision-making Australian football study (Lorains et al., 2013a) and contrary to the basketball study (Gorman & Farrow, 2009). We cannot suggest that this type of response is superior because no comparison was included in the current study. Our results do however contribute to the idea that a coupled task is not required to result in significant performance gains on the court.

Moreover, as mentioned previously, there is only one study that investigated the effect of the speed of videos during video simulation training on the on-court/on-field decision accuracy of Australian footballers (Lorains et al., 2013a). This study demonstrated significant transfer of performance gains for all groups; however their study was conducted during the competitive season of their participants. Therefore, the improvements are most likely due to physical practice more so than the video simulation training. The results of the current study revealed that videos of 100% speed led to positive transfer of performance gains. Furthermore, the current study was conducted during the participants' off-season; therefore physical practice was not a factor in the improvement. Finally, we cannot propose an optimal speed for transfer of performance gains because our study did not include a comparison between various speeds. However, our results contribute to the effectiveness of using videos of 100% speed during decision making video simulation training.

Moreover, as mentioned previously, it is still unclear how the size of the screen affects the transfer of performance gains. In the current study, the CS group used a 21.5-inch computer screen, while the VR group used a 5.5-inch smartphone. The absolute sizes of the screens are obviously different, however due to the shorter distance to the retina, the relative size of the objects in the VR condition was 30% larger than the CS condition. Certain authors speculate that "bigger is better" when it comes to the size of the screen (Broadbent et al., 2015 for review). Our results appear to support this hypothesis as the relative larger display could have contributed to the superior transfer of performance gains.

6.3 On-court transfer tests

In order to assess the level of transfer of performance between the laboratory and the field, researchers have mainly used one of two types of transfer tests: Actual competitive game film of the participants and mock-game scenarios. Both types of tests have strengths and limitations.

The competitive game film provides a natural setting to evaluate performance; it also includes factors such as anxiety and pressure (Gorman & Farrow, 2009). However, it has been proposed that the lack of control over the consistency of the opponent from pre to posttest may limit the ability to observe transfer (Gorman & Farrow, 2009). Furthermore, this method has also resulted in smaller sample sizes being eligible for data analysis. Participants are participating in regular physical practice and competitive matches. Therefore, if participants are injured during one or both of the on-court tests, they are excluded from data analysis. Furthermore, team dynamics change during the course of a competitive season and the playing time of athletes may also fluctuate. Therefore, if participants only partook in a small amount of playing time during the competitive matches for the on-court tests they are also excluded from data analysis. Finally, the level of control researchers have on the game-film scenarios is problematic as all of the plays during a competitive match are uncontrolled by the experimenters (Lorains et al., 2013a; Gorman & Farrow, 2009). Therefore, the plays evaluated during game-film scenarios were most likely "untrained" during the video simulation training due to the substantial amount of possible plays. The absence of positive transfer may be a result of video simulation training being play specific (Gorman & Farrow, 2009). These limitations are the main reason why the current study used the second type of transfer test, namely mock game scenarios.

The mock game scenarios test also included advantages and limitations. The mock games method allows for more controlled scenarios in order to assess the level of transfer of performance gains between training and on the field plays. Furthermore, all of the participants receive the same amount of transfer trials regardless of playing time during the competitive matches which increases the sample size for data analysis, which is not the case for the game-film analysis. Furthermore, this method allows researchers to determine whether their video simulation training led to play specific transfer (plays presented both during the on-field/on-court tests and during training) or if the transfer was generalized to novel plays (plays presented only during on-field/on-court tests). However, this method often fails to include the anxiety, pressure and fatigue factors involved during actual competitive match performance (Gray, 2017; Hopwood et al., 2011; Gabbett et al., 2007). It is still unclear which on-field test, competitive matches or mock games, should be used when assessing decision making skills. However, for the purpose of the current study, the mock games were utilized for several reasons. Firstly, this method allowed us to determine whether the computer screen modality and/or HMD virtual reality would result in play specific transfer or in generalization of learning from familiar to novel plays. Secondly, this method allowed us to determine the effect of video simulation training on on-court decision-making without physical practice and/or physical competitive matches being a contributing factor to the performance gains. Finally, this method allowed us to include all but one participant in the data analysis.

7. Conclusion

In the past few decades, video simulation training has been thoroughly investigated as an alternative and/or complementary training program to physical practice. Transfer of performance gains from the laboratory to the field/court has mainly been demonstrated for interceptive tasks, however more work needs to be done to determine the most effective video simulation training method for invasion tasks.

Moreover, in further studies it would interesting to include gaze behavior assessments for both types of viewing modalities to determine if they differ when viewing videos in HMD virtual reality compared to a computer screen. If gaze behavior differs, it could contribute to explaining the generalization of learning afforded by HMD virtual reality.

Finally, technological advances continue every year with improvements in the 360-degree cameras, the HMDs and the smartphones used to project the videos. Recently, camera companies have begun including advanced stabilization in their 360-degree cameras which improves the image quality while the camera is in movement. It is my personal opinion that, in the near future, researchers will be able to conduct studies using HMD virtual reality of basketball players in possession of the ball, thanks to this improved stabilization in the cameras. This would therefore open up the field to hundreds of more research opportunities in a variety of sports.

8. Annexe

8.1 Authorization to integrate the article submitted in the *Journal of Sports Sciences* to the present thesis

References

Abernethy, B., Baker, J., & Côté, J. (2005). Transfer of pattern recall skills may contribute to the development of sport expertise. *Applied Cognitive Psychology: The Official Journal of the Society for Applied Research in Memory and Cognition*, *19*(6), 705-718.

Abernethy, B., Gill, D. P., Parks, S. L., & Packer, S. T. (2001). Expertise and the perception of kinematic and situational probability information. *Perception*, *30*(2), 233-252.

Abernethy, B., Schorer, J., Jackson, R. C., & Hagemann, N. (2012). Perceptual training methods compared: the relative efficacy of different approaches to enhancing sport-specific anticipation. *Journal of experimental psychology: Applied*, *18*(2), 143.

Bideau, B., Kulpa, R., Vignais, N., Brault, S., Multon, F., & Craig, C. (2010). Using virtual reality to analyze sports performance. *IEEE Computer Graphics and Applications*, *30*(2), 14-21.

Brault, S., Kulpa, R., Duliscouët, L., Marin, A., & Bideau, B. (2015). Virtual Kicker vs. real goalkeeper in soccer : a way to explore goalkeeper's performance. *Movement & Sport Sciences*, (3), 79-88.

Breed, R., Mills, O., & Spittle, M. (2018). Can Video-based Perceptual-cognitive Tests Differentiate Between Skill Level, Player Position, and Experience in Elite Australian Football?.

Brenton, J., Müller, S., & Mansingh, A. (2016). Discrimination of visual anticipation in skilled cricket batsmen. *Journal of Applied Sport Psychology*, *28*(4), 483-488.

Broadbent, D. P., Causer, J., Ford, P., & Williams, A. M. (2015). Contextual interference effect on perceptual-cognitive skills training. *Medicine and Science in Sports and Exercise*, *47*(6), 1243-1250.

Broadbent, D. P., Causer, J., Williams, A. M., & Ford, P. R. (2015). Perceptual-cognitive skill training and its transfer to expert performance in the field: Future research directions. *European Journal of Sport Science*, *15*(4), 322-331.

Cañal-Bruland, R., & Schmidt, M. (2009). Response bias in judging deceptive movements. *Acta psychologica*, *130*(3), 235-240.

Carnegie, K., & Rhee, T. (2015). Reducing visual discomfort with HMDs using dynamic depth of field. *IEEE computer graphics and applications*, *35*(5), 34-41.

Casale, M. (2017). STRIVR Training Demonstrates Faster and More Accurate Learning Compared to Traditional Study Methods.

Christina, R. W., Barresi, J. V., & Shaffner, P. (1990). The development of response selection accuracy in a football linebacker using video training. *The Sport Psychologist*, *4*(1), 11-17.

Coles, M. G., Gratton, G., Bashore, T. R., Eriksen, C. W., & Donchin, E. (1985). A psychophysiological investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance*, *11*(5), 529.

Craig, C. (2013). Understanding perception and action in sport: how can virtual reality technology help?. *Sports Technology*, *6*(4), 161-169.

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. *Skill acquisition in sport: Research, theory and practice*, 112-130.

Dziuda, Ł., Biernacki, M. P., Baran, P. M., & Truszczyński, O. E. (2014). The effects of simulated fog and motion on simulator sickness in a driving simulator and the duration of after-effects. *Applied ergonomics*, *45*(3), 406-412.

Ericsson, K. A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. *The Cambridge handbook of expertise and expert performance*, *38*, 685-705.

Farrow, D. (2013). Practice-enhancing technology: a review of perceptual training applications in sport. *Sports Technology*, *6*(4), 170-176.

Gabbett, T., Rubinoff, M., Thorburn, L., & Farrow, D. (2007). Testing and training anticipation skills in softball fielders. *International Journal of Sports Science & Coaching*, *2*(1), 15-24.

Gokeler, A., Bisschop, M., Myer, G. D., Benjaminse, A., Dijkstra, P. U., van Keeken, H. G., ... & Otten, E. (2016). Immersive virtual reality improves movement patterns in patients after ACL reconstruction: implications for enhanced criteria-based return-to-sport rehabilitation. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(7), 2280-2286.

Gorman, A. D., Abernethy, B., & Farrow, D. (2012). Classical pattern recall tests and the prospective nature of expert performance. *Quarterly Journal of Experimental Psychology*, *65*(6), 1151-1160.

Gorman, A. D., Abernethy, B., & Farrow, D. (2013). Is the relationship between pattern recall and decision-making influenced by anticipatory recall?. *The Quarterly Journal of Experimental Psychology*, *66*(11), 2219-2236.

Gorman, A. D., & Farrow, D. (2009). Perceptual training using explicit and implicit instructional techniques: Does it benefit skilled performers?. *International Journal of Sports Science & Coaching*, *4*(2), 193-208.

Goulet, C., Bard, C., & Fleury, M. (1989). Expertise differences in preparing to return a tennis serve: A visual information processing approach. *Journal of sport and Exercise Psychology*, *11*(4), 382-398.

Gray, R. (2017). Transfer of Training from Virtual to Real Baseball Batting. *Frontiers in psychology*, *8*, 2183.

Gray, R. (in press). "Virtual environments and their role in developing and understanding perceptual-cognitive skills," in Anticipation and Decision Making in Sport, eds A. M.Williams and R. Jackson (Didcot: Taylor and Francis).

Holden, M. K. (2005). Virtual environments for motor rehabilitation. *Cyberpsychology & behavior*, *8*(3), 187-211.

Hopwood, M. (2009). The influence of viewing perspective on decision-making and visual search behaviour in an invasive sport. *Int. J. Sport Psychol*, *40*, 546564.

Hopwood, M. J., Mann, D. L., Farrow, D., & Nielsen, T. (2011). Does visual-perceptual training augment the fielding performance of skilled cricketers?. *International Journal of Sports Science & Coaching*, *6*(4), 523-535.

Houlston, D. R., & Lowes, R. (1993). Anticipatory cue-utilization processes amongst expert and non-expert wicketkeepers in cricket. *International Journal of Sport Psychology*, *24*(1), 59-73.

Jackson, R. C., & Farrow, D. (2005). Implicit perceptual training: How, when, and why?. *Human Movement Science*, *24*(3), 308-325.

Jackson, R. C., Warren, S., & Abernethy, B. (2006). Anticipation skill and susceptibility to deceptive movement. *Acta psychologica*, *123*(3), 355-371.

Juni, M. Z., Gureckis, T. M., & Maloney, L. T. (2016). Information sampling behavior with explicit sampling costs. *Decision*, *3*(3), 147.

Kida, N., Oda, S., & Matsumura, M. (2005). Intensive baseball practice improves the Go/Nogo reaction time, but not the simple reaction time. *Cognitive brain research*, *22*(2), 257-264.

Kinrade, N. P., Jackson, R. C., & Ashford, K. J. (2015). Reinvestment, task complexity and decision making under pressure in basketball. *Psychology of Sport and Exercise*, *20*, 11-19.

Kulpa, R., Multon, F., & Argelaguet, F. (2016, May). VIRTUAL REALITY & SPORT. In *ISBS-Conference Proceedings Archive*(Vol. 33, No. 1).

Jungjin Kim PT, M. S., & BumChul Yoon, P. T. (2016). Patient perspectives on virtual reality-based rehabilitation after knee surgery: Importance of level of difficulty. *Journal of rehabilitation research and development*, *53*(2), 239.

Lintern, G. (1991). An informational perspective on skill transfer in human-machine systems. *Human Factors*, *33*(3), 251-266.

Lorains, M., Ball, K., & MacMahon, C. (2013a). An above real time training intervention for sport decision making. *Psychology of Sport and Exercise*, *14*(5), 670-674.

Lorains, M., Ball, K., & MacMahon, C. (2013b). Expertise differences in a video decision-making task: Speed influences on performance. *Psychology of Sport and Exercise*, *14*(2), 293-297.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology*, *29*(4), 457-478

Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends in cognitive sciences*, *9*(6), 296-305.

Miles, H. C., Pop, S. R., Watt, S. J., Lawrence, G. P., & John, N. W. (2012). A review of virtual environments for training in ball sports. *Computers & Graphics*, *36*(6), 714-726.

Miller, R. (1954). Psychological considerations in the design of training equipment. *Report no. WADC-TR 54-563, AD 71202* Wright Patterson Air Force BAse, OH; Wright Air Development Center. Wright-Patterson Air Force Base.

"NBA Extends Television Deals." *ESPN*, ESPN Internet Ventures, 14 Feb. 2016, www.espn.com/nba/story/_/id/11652297/nba-extends-television-deals-espn-tnt.

Müller, S., & Abernethy, B. (2012). Expert anticipatory skill in striking sports: A review and a model. *Research Quarterly for Exercise and Sport*, *83*(2), 175-187.

Murgia, M., Sors, F., Muroni, A. F., Santoro, I., Prpic, V., Galmonte, A., & Agostini, T. (2014). Using perceptual home-training to improve anticipation skills of soccer goalkeepers. *Psychology of Sport and Exercise*, *15*(6), 642-648.

Poulter, D. R., Jackson, R. C., Wann, J. P., & Berry, D. C. (2005). The effect of learning condition on perceptual anticipation, awareness, and visual search. *Human Movement Science*, *24*(3), 345-361.

Put, K., Wagemans, J., Jaspers, A., & Helsen, W. F. (2013). Web-based training improves on-field offside decision-making performance. *Psychology of Sport and Exercise*, *14*(4), 577-585.

Ranganathan, R., & Carlton, L. G. (2007). Perception-action coupling and anticipatory performance in baseball batting. *Journal of Motor Behavior*, *39*(5), 369-380.

Reilly, A. W. T., & Williams, A. M. (2000). Talent identification and development in soccer. *Journal of Sports Sciences*, *18*(9), 657-667.

Renshaw, I., & Fairweather, M. M. (2000). Cricket bowling deliveries and the discrimination ability of professional and amateur batters. *Journal of Sports Sciences*, *18*(12), 951-957.

Ripoll, H., Kerlirzin, Y., Stein, J. F., & Reine, B. (1995). Analysis of information processing, decision making, and visual strategies in complex problem solving sport situations. *Human Movement Science*, *14*(3), 325-349.

Robert, M. T., Ballaz, L., & Lemay, M. (2016). The effect of viewing a virtual environment through a head-mounted display on balance. *Gait & posture*, *48*, 261-266.

Ryu, D., Abernethy, B., Mann, D. L., Poolton, J. M., & Gorman, A. D. (2013). The role of central and peripheral vision in expert decision making. *Perception*, *42*(6), 591-607.

Salamin, P., Tadi, T., Blanke, O., Vexo, F., & Thalmann, D. (2010). Quantifying effects of exposure to the third and first-person perspectives in virtual-reality-based training. *IEEE Transactions on Learning Technologies*, *3*(3), 272-276.

Savelsbergh, G. J., Haans, S. H., Kooijman, M. K., & Van Kampen, P. M. (2010). A method to identify talent: Visual search and locomotion behavior in young football players. *Human movement science*, *29*(5), 764-776.

Schmidt, R. A., Lee, T., Winstein, C., Wulf, G., & Zelaznik, H. (2018). *Motor Control and Learning, 6E*. Human kinetics.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological review*, *84*(1), 1.

Shin, J. H., Kim, M. Y., Lee, J. Y., Jeon, Y. J., Kim, S., Lee, S., ... & Choi, Y. (2016). Effects of virtual reality-based rehabilitation on distal upper extremity function and health-related quality of life: a single-blinded, randomized controlled trial. *Journal of neuroengineering and rehabilitation*, *13*(1), 17.

Smeeton, N. J., Williams, A. M., Hodges, N. J., & Ward, P. (2005). The relative effectiveness of various instructional approaches in developing anticipation skill. *Journal of Experimental Psychology: Applied*, *11*(2), 98.

Standen, P. J., Threapleton, K., Richardson, A., Connell, L., Brown, D. J., Battersby, S., ... & Burton, A. (2017). A low cost virtual reality system for home based rehabilitation of the arm following stroke: a randomised controlled feasibility trial. *Clinical rehabilitation*, *31*(3), 340-350.

Vicente, K. J., & Wang, J. H. (1998). An ecological theory of expertise effects in memory recall. *Psychological review*, *105*(1), 33.

Vickers, J. N. (1992). Gaze control in putting. *Perception*, *21*(1), 117-132

Vignais, N., Kulpa, R., Brault, S., Presse, D., & Bideau, B. (2015). Which technology to investigate visual perception in sport: Video vs. virtual reality. *Human movement science*, *39*, 12-26.

Williams, A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of sports sciences*, *18*(9), 737-750.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research quarterly for exercise and sport*, *69*(2), 111-128.

Williams, A. M., Ward, P., & Chapman, C. (2003). Training perceptual skill in field hockey: Is there transfer from the laboratory to the field?. *Research quarterly for exercise and sport*, *74*(1), 98-103.

Williams, A. M., Ward, P., Knowles, J. M., & Smeeton, N. J. (2002). Anticipation skill in a real-world task: measurement, training, and transfer in tennis. *Journal of Experimental Psychology: Applied*, *8*(4), 259.

Zahorik, P., & Jenison, R. L. (1998). Presence as being-in-the-world. *Presence*, *7*(1), 78-89.